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Approach to supracondylar humerus fractures with neurovascular compromise in children

Murat AKSAKAL[1], Cenk ERMUTLU[2], Bartu SARISÖZEN[3], Burak AKESEN[3]

[1]Department of Orthopedics and Traumatology, Yüksek İhtisas Training and Research Hospital, Bursa, Turkey;
[2]Department of Orthopedics and Traumatology, Polatlı Duatepe State Hospital, Ankara, Turkey
[3]Department of Orthopedics and Traumatology, Faculty of Medicine, Uludağ University, Bursa, Turkey

Objective: The aim of this study was to evaluate neurovascular compromise in childhood Gartland Type 3 supracondylar humerus fractures (SHFs), identify the factors correlated with increased need of open reduction and compare the clinical outcome of anterior open reduction with that of closed reduction.

Methods: The study included 65 patients (46 male, 19 female; mean age: 7.03 years, range: 1 to 14 years) treated surgically for SCH fracture between January 2002 and June 2008. Fractures underwent closed reduction with percutaneous pinning when possible. Open reduction was performed when adequate reduction via the closed technique failed or vascular compromise were indications for open reduction. Patient demographics, physical examination findings, adequacy of reduction, functional and cosmetic outcomes were assessed.

Results: During the antecubital approach, vascular pathology was noted in all patients with signs of vascular compromise at physical examination. Half of these patients underwent vascular intervention. Closed reduction failed in 93% of patients with concomitant edema, ecchymosis and dimple sign. Of these, the median nerve was trapped between the bone fragments in 4 patients with normal neurological examinations. Functional and cosmetic results of open reduction were similar to closed reduction (p>0.05).

Conclusion: Closed reduction should not be forced in cases with marked edema, ecchymosis, dimple sign, and absence of radial pulse. The anterior approach is the surgical approach of choice due to direct visualization of neurovascular bundle and availability of neurovascular intervention by extending the same approach.

Key words: Antecubital; anterior approach; closed reduction; neurovascular compromise; supracondylar humerus fracture.

Supracondylar humerus fractures (SHF) are grouped as either extension or flexion type fractures based on the distal fragment's direction of translation. Extension type fractures are further divided into 3 subgroups depending on the degree of displacement as described by Gartland.[1] Treatment method is based on this classification. Both open and closed reduction techniques have been used for the treatment of Gartland Type 3 fractures with maximum displacement.

Closed reduction and percutaneous pinning is the first line treatment for childhood SHFs.[2,3] However, indications for open reduction and the preferable surgical approach remain controversial.[4,5] Open fractures and vascular compromise are generally accepted indi-

Correspondence: Cenk Ermutlu, MD. Polatlı Duatepe Devlet Hastanesi, Ortopedi ve Travmatoloji Kliniği, Ankara, Turkey.
Tel: +90 532 - 626 35 36 e-mail: cermutlu@hotmail.com
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cations for open reduction although vascular compromise necessitating open approach has been described differently by various authors.[1,2,6-9]

Open reduction of SHF can be achieved via the anterior, medial, lateral or posterior approach. The anterior approach is not a routine method in the treatment of these fractures and is usually performed in the presence of concomitant neurovascular pathology. The need to explore the neurovascular bundle in order to reach the fracture line is a possible concern for surgeons when considering the anterior cubital approach.[3]

In this study, we aimed to evaluate neurovascular compromise in childhood SHFs, identify the factors correlated with increased need of open reduction and compare the clinical outcome of anterior open reduction with that of closed reduction.

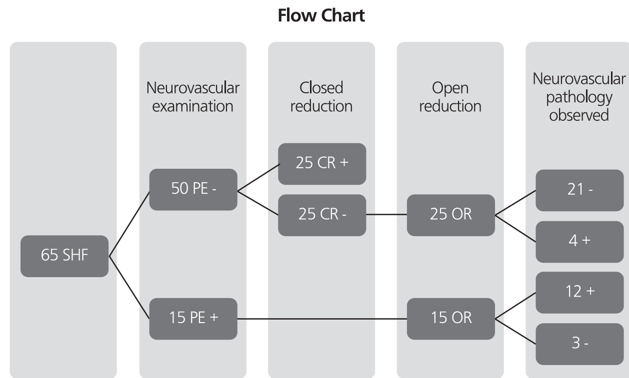

Fig. 1. Flow diagram of treatment algorithm for supracondylar humerus fractures in children. CR -: closed reduction unsuccessful, CR +: closed reduction successful, OR: open reduction, PE -: physical examination negative for neurovascular compromise, PE +: physical examination positive for neurovascular compromise, SHF: supracondylar humerus fracture.

Patients and methods

Sixty-five children (46 male, 19 female; mean age: 7.03 years, range: 1 to 14 years) who sustained Gartland Type 3 SHFs between January 2002 and June 2008 and completed the follow-up were enrolled in the study. Patients with concomitant systematic injuries or with a history of elbow fracture at the ipsilateral side were excluded.

Patients were evaluated for the presence of marked edema, dimple sign, diffuse ecchymosis, neurovascular insult and concomitant injuries at the time of initial presentation. Standard treatment of displaced fractures was closed reduction and percutaneous pinning. Open reduction was carried out for cases with vascular compromise, open fractures and fractures which were imperfectly reduced despite two attempts in the operating room. Vascular compromise was defined as absence of peripheral pulses, weak or no recovery of the pulse after closed reduction in the emergency room or poor perfusion of the hand at the initial presentation. The treatment algorithm based on physical examination is presented as a flow chart in Fig. 1. Doppler ultrasonography was used to assess peripheral circulation in cases with suspicion of vascular compromise upon physical examination. Neurological examination was performed by comparing with the uninvolved limb. Neurovascular examination was noted and later compared with the observed status during open surgery.

Both open and closed reductions were performed under general anesthesia with the patient in the supine position. Closed reduction and fixation was achieved via routine percutaneous cross-pin technique, beginning on the lateral side. If fracture reduction was not adequate in AP and lateral views after two closed attempts, the surgeons moved on to anterior open reduction.

For the anterior open reduction technique, a 2 cm transverse incision was made on the antecubital region beginning where the ecchymosis was most evident, following the flexor crease. The brachial artery, median nerve and, if necessary, radial nerve were explored. The neurovascular bundle and soft tissues tethered or trapped between the bone fragments were released. Reduction was achieved through manual manipulation of the fragments. The reduction was assessed by palpating the lateral and medial columns for any step or overlapping which indicates rotational malalignment. Fixation was achieved with two cross-pins. Neurovascular structures were examined for laceration, contusion, thrombosis or rupture. When necessary, the incision was enlarged in the proximal or distal directions and vascular repair was performed by vascular surgeons. At the end of the procedure, the position of the pins and reduction were evaluated using fluoroscopy or radiographs.

Patients were followed up weekly and any complications, such as wound infection, pin tract infection, loss of reduction or neurological problems were noted. Splints and K-wires were removed 3 weeks after the surgery. At the end of the 4th postoperative week, AP and lateral radiographs were taken. Baumann and lateral humerocapitellar angles were measured. To finalize the study, patients with adequate documentation of previous follow-up were reached by telephone and invited for a follow-up visit. Sixty-five patients showed up for this last visit.

Informed consent was obtained for all patients. Radiographic measurements were recorded for both the injured and uninvolved limbs. Functional and cosmetic outcomes were assessed using Flynn's criteria based on range of motion and carrying angle measurements (Table 1).

Statistical analyses were performed using SPSS 13.0 (Statistical Package for Social Sciences; SPSS Inc., Chicago, IL, USA). Normal distribution of variables was analyzed using Kolmogorov-Smirnov and Shapiro-Wilk tests and continuous variables were analyzed using the Mann-Whitney U test. Nominal variables were analyzed using Pearson's chi-squared and Fisher's exact tests. Accuracy and usefulness of vascular physical examination to detect pathologies were assessed by constructing a standard 2×2 table.

Results

Closed reduction was performed in 25 (38.4%) and open reduction in 40 (61.6%) patients. The mean period of time from injury to the final follow-up was 25.9 (range: 12 to 83) months in the closed reduction patients and 20.3 (range: 12 to 72) months in the open reduction cases. The mean age of open reduction patients was significantly greater (p<0.05). There was no significant difference between the two groups in terms of gender (p>0.05). The hospital stay and anesthesia time were significantly longer in open reduction patients (p<0.05) (Table 2). None of the patients experienced complications, such as delayed union, nonunion, pin tract infection, myositis ossificans or malunion.

The treatment algorithm based on neurovascular examination is presented as a flow chart in Fig. 1. Closed reduction was initially attempted in 50 patients with no sign of vascular compromise at the time of presentation. Of these 50 patients, 25 were successfully managed with closed reduction. The remaining 25 patients underwent open reduction after 2 unsuccessful closed reduction attempts. Diffuse ecchymosis, edema and dimple sign were observed in 3 patients managed with closed reduction and 23 out of 25 patients in who closed reduction was unsuccessful (Table 3). Open reduction was performed without first attempting closed reduction in 15 of 65 patients due to vascular compromise confirmed with Doppler ultrasound. All patients with vascular findings also had diffuse ecchymosis, edema and dimple sign of the proximal fragment in subcutaneous tissue (Fig. 2).

Actual vascular injury or entrapment of the neurovascular bundle between fracture ends were demonstrated in 12 (80%) of 15 patients who underwent open surgery without prior closed reduction attempt (Fig. 3). Vascular surgeons performed primary repair of brachial artery in 2 cases, repair of brachial artery by grafting in one case and embolectomy of the brachial, radial, and ulnar arteries in another. Entrapped brachial artery was released from surrounding fracture edges in eight cases. None of the patients had persistent circulatory compromise after surgical intervention. No vascular pathology was observed in the patients who underwent open reduction following two unsuccessful closed reduction attempts. Overall, non-invasive examination on children with SHF revealed high sensitivity (1.00), specificity (0.89), positive (0.80) and negative (1.00) predictive values for detecting vascular pathologies.

Table 1. Flynn's criteria.

	Cosmetic factor	Functional factor
	Changes in the carrying angle	Motion restriction
Excellent	0-5 degrees	0-5 degrees
Good	6-10 degrees	6-10 degrees
Fair	11-15 degrees	11-15 degrees
Poor	>15 degrees	>15 degrees

Table 2. Demographic data of the patients.

	Gender	Age	Hospital stay (days)	Anesthesia length (minutes)
OR (n=40)	M: 77.5% F: 22.5%	7.7±2.79	2.2±1.87	118.00±71.10
CR (n=25)	M: 60.0% F: 40.0%	5.96±2.50	1.2±1.10	71.60±28.71
P value	p>0.05	p<0.05	p<0.05	p<0.05

CR: closed reduction; F: female; M: male; OR: open reduction.

Table 3. Relation between soft tissue damage and closed reduction attempts.

	Marked ecchymosis edema, dimple sign +	Marked ecchymosis, edema, dimple sign -
CR -	23	2
CR +	3	22

CR -: closed reduction unsuccessful; CR +: closed reduction successful.

Fig. 2. Marked ecchymosis and swelling in a child with no neurovascular compromise. Severe soft tissue damage and failed closed reduction attempts led to open reduction through anterior approach. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

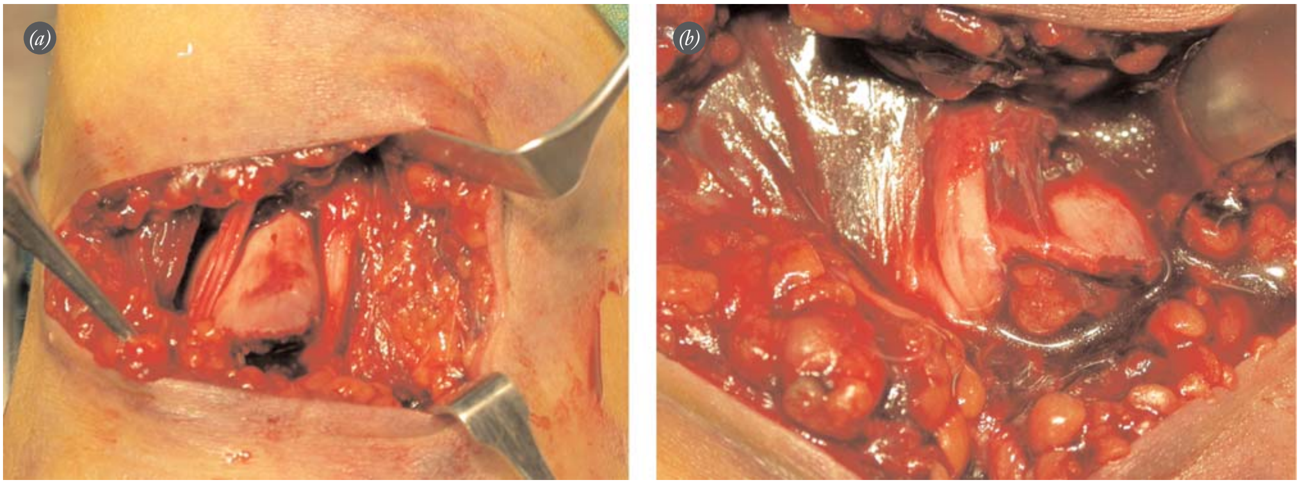

Fig. 3. **(a)** Median nerve and brachial artery are tethered over the bone spike. **(b)** Neurovascular bundle is released. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

Eight patients who underwent anterior open reduction because of vascular compromise had concomitant neurologic findings preoperatively. Intraoperative examination yielded median nerve entrapment in four cases and entrapment of both median and radial nerves in one case. Contusion and epineural laceration of these neurologic structures were observed and decompression and neurolysis performed. Of the 25 patients who underwent open reduction due to failed closed reduction attempt, 4 patients (16%) with normal preoperative neurological examination were perioperatively noted to have median nerve entrapment between fracture ends. Releasing the tethered neural tissues prior to reduction was sufficient in these patients. Signs associated with nerve injury completely recovered in 3 weeks in eight cases and in 6 weeks in one case.

Mean Baumann and lateral humerocapitellar angle measurements in the first visit yielded similar results in both groups ($p>0.05$) (Table 4). However, mean Baumann and mean lateral humerocapitellar angles measured at the final follow-up visit were significantly higher in patients who had undergone open reduction ($p<0.05$). Although mean angles were different between the two groups, these values were within the normal range for both groups. When the fractured and non-fractured humeri of the patients were compared, the differences were observed to be similar in both groups. There was no significant difference between the groups in terms of the carrying angle and change in the carrying angle ($p>0.05$.).

No significant differences between the fractured and non-fractured sides were observed in flexion, extension and loss of total range of motion between the two groups ($p>0.05$). There was no significant difference between the two groups in terms of cosmetic and functional results according to Flynn's criteria (Table 5).

Discussion

The primary treatment modality for displaced SHFs is closed reduction with percutaneous pinning. Advantages of this method include short operation and hospitalization time, low infection rates and the preservation of the fracture hematoma. However, potential drawbacks include radiation exposure for both the surgeon and patient and the risk of iatrogenic nerve injury, especially in the ulnar nerve (1.4%-15.6%).[10,11] Open reduction with percutaneous pinning may also be used although

Table 4. Adequacy of reduction.

Group	Initial follow-up		Last follow-up			
	Baumann angle	Humerocapitellar angle	Baumann angle	Humerocapitellar angle	Δ Baumann angle	Δ Humerocapitellar angle
OR	12.72 ±5.81°	44.70±14.20°	14.62±5.32°	47.17±13.49°	3.42±3.35°	8.32±7.42°
CR	11.04±3.59°	39.28±8.62°	10.60±4.37°	41.16±11.52°	3.48±4.24°	7.04±8.21°
p	p>0.05	p>0.05	p<0.05	p<0.05	p>0.05	p>0.05

Δ Baumann angle: difference between the Baumann angles of the fractured elbow at the last follow-up and the intact limb; Δ Humerocapitellar angle: difference between the humerocapitellar angles of the fractured elbow at the last follow-up and the intact llimb, CR: closed reduction, OR: open reduction.

indications for open reduction and the preferable surgical approach are controversial.[4,5] Open fractures and vascular compromise are generally accepted indications for open reduction without first attempting closed reduction. We used these criteria for open reduction in our study.

Circulatory compromise of the extremity is a serious complication of SHF and may result in such devastating situations as compartment syndrome. While authors such as Gartland and Danielson consider the absence of pulse at presentation and weak or no recovery after reduction as indications for exploration,[1,4,6,7,9] others state that signs of peripheral ischemia are necessary to justify exploration.[2,12] In our study, we accepted the absence of pulse and weak or no recovery of the pulse after reduction as signs of vascular compromise and directly moved on to open reduction. Actual vascular injury (4 cases) or entrapment of the neurovascular bundle between fracture ends (8 cases) were demonstrated in 80% of patients who underwent open surgery without prior closed reduction attempt (Fig. 3). None of the patients had persistent circulatory compromise after surgical intervention. No vascular pathology was observed in the patients who underwent open reduction following two subsequent unsuccessful close reduction attempts. In addition to studies reporting a high sensitivity of absent or diminished pulse on presentation,[13] our results also indicate that an absent pulse which does not recover after reduction is a valuable non-invasive finding with high sensitivity (1.00), specificity (0.89), positive (0.80) and negative (1.00) predictive values for detecting vascular pathologies. Although preoperative neurologic deficit is not an indication for surgical exploration, we noted that 5 out of 8 patients with concomitant vascular compromise and neurological deficit had varying degrees of intraoperative nerve lesions (Fig. 3). In light of these findings, concomitant pulse deficit and presence of neurological findings should warn surgeons to lower their threshold for proceeding with open surgery.

In our series, open reduction was performed after two unsuccessful closed reduction attempts. This resulted in a higher number of open reductions than the literature. However, the median nerve was trapped in the fracture line in 4 of the irreducible cases. In a case report on two SHFs with failed closed reduction attempts, Elstrom et al. reported that closed reduction failed because of entrapment of the median nerve and brachial artery between bone fragments.[14] Similarly, Fleuriau-Chateau et al.[15] observed entrapment or tethering of the neurovascular structures in 15 cases during open reduction of 41 irreducible SHFs. They concluded that preoperative neurovascular deficit is not predictive of entrapment and recommended the lowering of the threshold, given certain appropriate indicators. In a study by Louahem et al., 3 of 26 patients with pulseless hand underwent surgical exploration due to imperfect reduction and noted entrapment of the brachial artery and median nerve at the fracture site in each case.[16] Our similarly high incidence of undetected neurovascular entrapment (16%) in cases with extreme soft tissue damage justifies direct open reduction with anterior approach in these instances.

Of the 25 cases with failed closed reduction attempts, 23 had concurrent marked ecchymosis, edema and dimple sign. Of the remaining 25 cases with successful closed reduction, only three cases had these signs. Accompanying marked ecchymosis, edema and dimple sign are signs of extreme soft tissue damage and can be interpreted as forewarning of difficult closed reduction. Supracondylar fractures presenting with excessive swelling and ecchymosis documented at presentation should be considered to have increased risk of developing compartment syndrome and limb ischemia even in the presence of an intact radial pulse.[8]

Controversy regarding the ideal method of open reduction remains with several studies having depicted the advantages and disadvantages of different surgical exposures. Usually, the anterior approach is avoided when the neurovascular structures are located on the antecubital region.[3] In our study, exploration of the neurovascular bundle was performed through the same antecubital incision used for reduction. Vascular surgeons performed necessary interventions by extending the incision in proximal or distal direction in 4 cases with vascular injury. Anterior open reduction renders possible simultaneous examination of neurovascular pathologies and necessary interventions.

Table 5. Functional and cosmetic outcome.

	Excellent good cosmetic*	Excellent good function*	Flexion loss	Extension loss	Carrying angle	Δ Carrying angle
OR Group n (%)	39 (97.5)	36 (90.0)	2.8°±7.8°	0.9°±3.2°	9.6±4.1°	3.1±3.1°
CR Group n (%)	24 (96)	24 (96.0)	1.2°±4.2°	0.00°±0.00°	9.00±3.9°	2.4±2.8°
P value	p>0.05	p>0.05	p>0.05	p>0.05	p>0.05	p>0.05

*According to Flynn's criteria. Δ Carrying angle: difference between the carrying angles of the fractured and intact limb, CR: closed reduction, OR: open reduction.

With the exception of the anterior antecubital approach, all approaches require dissection through the intact side of the elbow. Among these, the posterior approach creates serious problems for the regaining of elbow range of motion due to the dissection of the intact triceps muscle.[17-19] In our study, the fracture site and neurovascular bundle were reached through a small incision on the ecchymosis with blunt dissection through the ruptured muscle planes without additional soft tissue dissection. As a result, patients who underwent open reduction had similar functional and cosmetic outcome as those in the closed reduction group (Table 5).

In this study, fluoroscopic or radiographic control of open reduction was performed at the end of surgery only in order to reduce radiation exposure. As the periosteum is already stripped at the time of the injury, palpation of the medial and lateral columns of the supracondylar humerus is undemanding. Palpation of the medial condyle helps not only to reduce the fracture with limited radiation exposure, but also makes the orientation easier during the application of the medial K-wire. Despite limited fluoroscopic guidance, reduction was still within ideal limits, as was demonstrated by the carrying, Baumann and humerocapitellar angles. The only disadvantages of open anterior reduction are prolonged hospitalization and operation time. When compared to closed reduction with percutaneous pinning, the open anterior technique has no additional complication risks and carries less risk of iatrogenic neurovascular damage by facilitating direct visualization of these structures.[3,18]

In conclusion, closed reduction with percutaneous pinning is the preferred method of treatment for displaced SHFs in children. Open reduction should be attempted when signs of severe soft tissue damage or neurovascular compromise are present, closed reduction attempts fail, the patient age is relatively old or the time from trauma to admission is prolonged. The easy and complete access to the fracture site, direct visualization of the neurovascular structures, manipulation of soft tissues trapped between fragments and preventing reduction, fluoroscopy redundancy, cosmetic recovery of skin incision and possibility of extending the incision proximally or distally make the anterior approach ideal when open reduction is indicated.

Conflicts of Interest: No conflicts declared.

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